StructureWorks Precast –
Mathcad 13 integration overview.

Written By:
StructureWorks, LLC

5801 North Pecos Street
Denver, Colorado 80221

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Introduction

Three dimensional computer-aided design (CAD) systems have been used in architectural applications for decades but traditionally avoided in precast construction due to the inability of associated software to be both cost-effective and feature-rich. Not only has CAD been slow to be adopted but integrated solutions for engineering design have been even slower to be developed let alone be adopted. While many other industries have had CAD integrated with analysis and design solutions, most of these revolve around Finite Element Analysis (FEA) applications.

Many of the manufactured concrete analysis and design solutions involve hand calculations, Microsoft® Excel files, or Mathcad™ worksheets. Integration of these tools for additional engineering automation has been very limited. The integration presented in this paper outlines some of the features and benefits of the integration between StructureWorks™ Precast and Mathcad™. This link bridges the gap between CAD modeling and engineering analysis and design.

StructureWorks has developed two approaches to this integration, User specific and StructureWorks specific. The user integration is the most robust and open while the StructureWorks specific is for a specific set of design or analysis tasks. The User Specific method is presented in this paper.

With this first in technology for this market place, **any** Mathcad™ 13 worksheet can be linked to any cad geometry. This link can be bi-directional allowing data to be sent between the two application or one way, allowing on one way data transfer. Linking both new and existing worksheets is a simple procedure and offers the ability to automate nearly every engineering design function. Now any product or component geometry can be used for analysis, or better yet the design of these components can be completely automated. This paper outlines and describes key features specific to this integration.

User Specific Data Transfer Overview

In summary a Mathcad sheet is attached to a StructureWorks Part or Assembly document through the SolidWorks® design binder. Variables in both documents are transferred between the two applications and the results can be stored in the Part, Assembly, and Mathcad files. In addition to dimensional values; features, database objects, and user inputs can be transferred between the files as well. There is visual notification if the model has changed from that last time it was designed or analyzed. Conditional alerts can be set up for user notification as well as return messages regarding the design or analysis. These messages are saved for additional review or for others to see when they open the file.

Design binder

The Design Binder is a folder in any SolidWorks file. The folder is a repository for the attachment of additional files. These files can be Embedded or linked Microsoft Word®, Microsoft Excel®, PDF, or other types of documents containing proposals, quotes, calculations, catalogs of purchased parts, design failure analyses, problem logs, reports, etc.

In every StructureWorks part or assembly there is a document called **Design Journal.doc** that is embedded in SolidWorks documents. The document has the following properties:
Appears in the Design Binder folder in the FeatureManager design tree.

- Is a embedded Microsoft Word® document.
- Resembles an engineering journal, with headings for File Name, Description, and Material. These fields are linked to document properties and updated whenever the journal is opened. File Name is the actual file name and Description and Material are SolidWorks document custom properties.
- Appears initially as <Empty>, a designation that disappears when you activate the journal. Can be deleted, in which case it is again listed as <Empty>.
- Accepts both text and embedded images.

For the StructureWorks Precast integration to be enabled we embed a Mathcad 13 worksheet or multiple worksheets.

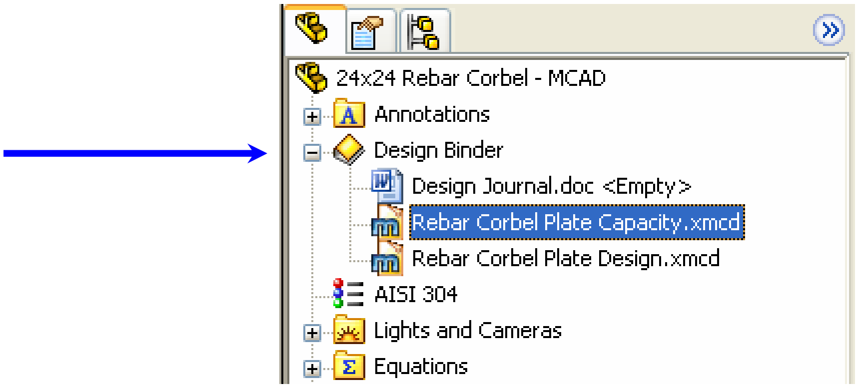

Figure 1 - SolidWorks® Design Binder

Any number of Mathcad Worksheet files can be place in the Design Binder for use in the analysis or design. These files are saved with the part file or can be saved to an alternate location.

Variables

StructureWorks Precast provides the user the ability to transfer variables from the StructureWorks Precast model to the Mathcad worksheet and in reverse. The method is simple and straight forward. Any dimension or feature in the model can be named in a fashion than when an analysis of the variables is performed; StructureWorks traverses the names and passes Mathcad only the appropriate ones.

Dimensions

In Figure 2 a set of user dimensions have been placed on a sketch with reference to plate geometry. Both Bottom-Up Design[1] relationships and Top-Down Design[2] relationships can exist for reference values. When this plate is inserted with a connection or as an embed, if Top-Down relationships exist, any Top-Down relationship that modifies the plate geometry will automatically be reflected in these values.

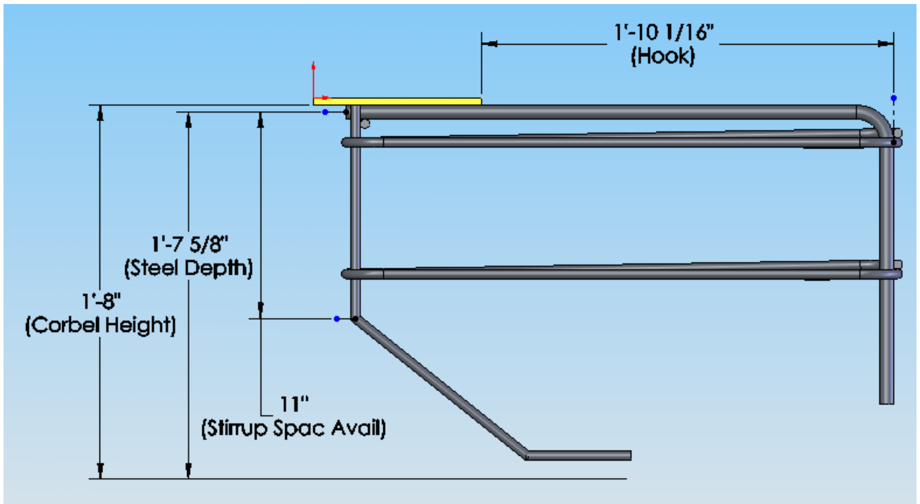

Figure 2 – Dimension Names

Figure 2 also illustrates the Dimension names, (Corbel Height), (Steel Depth), etc. of the dimension string. These names can be the default SolidWorks name or for convenience they can be user defined as in this case. These names represent the variables that will be passed to the Mathcad worksheet.

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[1] [1] Bottom-up Design - Bottom-up design is the traditional method. In bottom-up design, you create parts, insert them into an assembly, and mate them as required by your design. Bottom-up design is the preferred technique when you are using previously constructed, off-the-shelf parts. Source – *SolidWorks® 2006 Online User Guide*

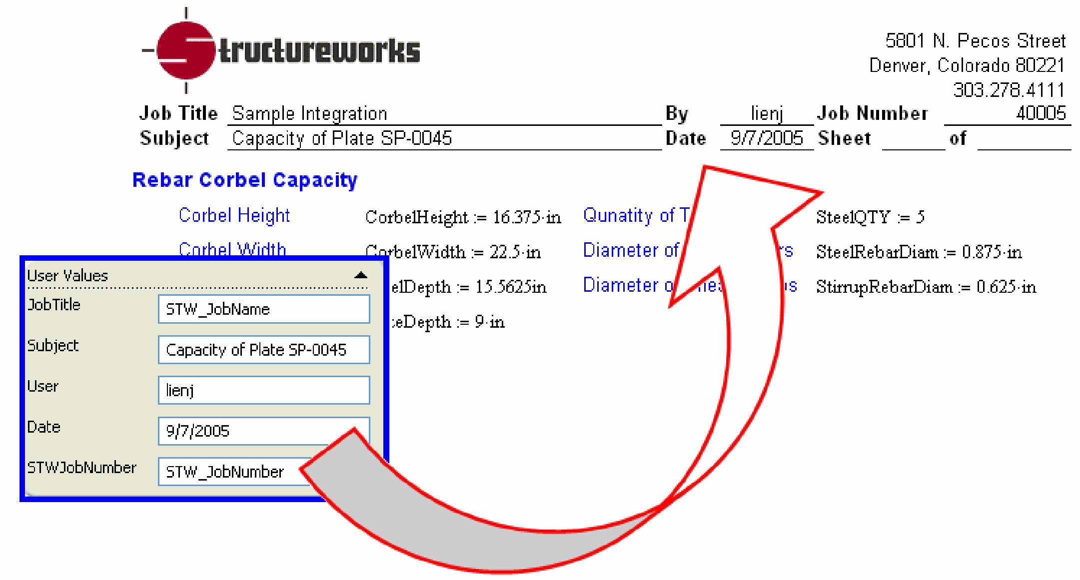
[2] Top-down Design - Top-down design is different because you start your work in the assembly. You can use the geometry of one part to help define other parts, or to create machined features that are added only after the parts are assembled. You can start with a layout sketch define fixed part locations, planes, and so on, then design the parts referencing these definitions. Source – *SolidWorks® 2006 Online User Guide*

In order for Mathcad to understand that a dimension in the StructureWorks model is to be used in the Mathcad worksheet, the Mathcad variable will need a **Tag**. For proper communication between the StructureWorks Model and the select Mathcad worksheet, the **Tag** name will be constructed of an *STW-* concatenated to the dimension name from the model, I.E. *STW-Corbel Height.*

The link is now complete. If the dimension in the model is *driving*, I.E. the dimensional value will modify geometry, then any changes in that value calculated by the Mathcad worksheet will modify the geometry in the StructureWorks model. If the Dimension in the model is *Driven*, I.E. the dimensional value will not control model geometry, then any changes in the value from StructureWorks Precast will modify the Mathcad worksheet.

User Values

In addition to dimensions, support of any variable either from the robust StructureWorks Database or User Defined can be sent either from StructureWorks Precast to Mathcad or in reverse. An example is automatic population of a calculation sheet header, the engineer can automatically fill out the Job number, Job Name, Design Engineer. The *StW_* in the name indicates a call to a query from the StructureWorks Precast Database.



5801 N. Pecos Street
Denver, Colorado 80221
303.278.4111

Job Title	Sample Integration	**By**	lienj	**Job Number**	40005		
Subject	Capacity of Plate SP-0045	**Date**	9/7/2005	**Sheet**		**of**	

Rebar Corbel Capacity

Corbel Height CorbelHeight := 16.375·in

Corbel Width CorbelWidth := 22.5·in

elDepth := 15.5625in

:eDepth := 9·in

Qunatity of T SteelQTY := 5

Diameter of rs SteelRebarDiam := 0.875·in

Diameter o ne s StirrupRebarDiam := 0.625·in

User Values

JobTitle	STW_JobName
Subject	Capacity of Plate SP-0045
User	lienj
Date	9/7/2005
STWJobNumber	STW_JobNumber

Figure 3 – User and Database Values

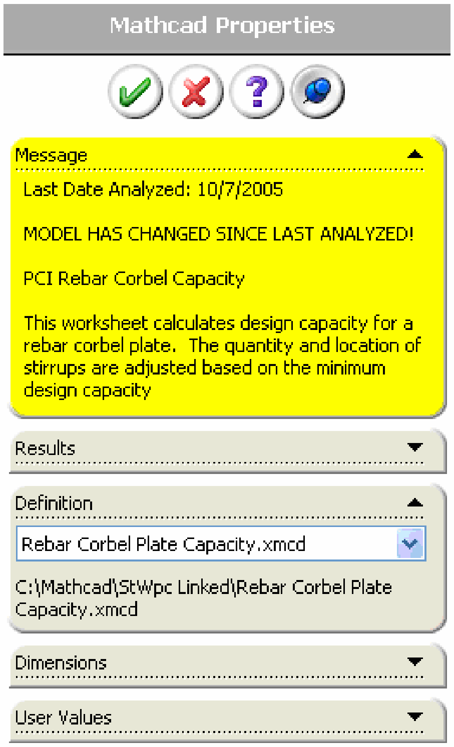
Recalling that StructureWorks Precast sits on Microsoft SQL Server, utilizing this connection, data from any modeled part or from any other department within the enterprise may be obtained.

Feature Data

In addition to dimensional values, an additional necessity is the ability to pass Feature data. Within StructureWorks Precast features represent a modeled part, a piece of rebar, a layer or multiple layers of mesh. Sending data to an analysis or design application for inclusion or exclusion of these features for simplifying the mathematical problem is very important. In addition to simplifying the design problem, one needs the ability to edit the features or Suppress and Un-suppress specific entities based on the design output, I.E adding shear rebar or subtracting a layer of mesh.

Integration UI

StructureWorks Precast is a fully integrated solution with the SolidWorks cad platform. Nearly all the StructureWorks Precast Graphical User Interface (GUI) utilizes the SolidWorks Heads-Up Display or Property Page. The StructureWorks Mathcad integration is no different.



Last Date Analyzed: 10/7/2005

MODEL HAS CHANGED SINCE LAST ANALYZED!

PCI Rebar Corbel Capacity

This worksheet calculates design capacity for a rebar corbel plate. The quantity and location of stirrups are adjusted based on the minimum design capacity

Rebar Corbel Plate Capacity.xmcd

C:\Mathcad\StWpc Linked\Rebar Corbel Plate Capacity.xmcd

Figure 4 - StructureWorks Precast Mathcad Property Page

The Property Page resides on the left side of the screen allowing as much model interaction as possible. This provides ease of variable checking and adding dimensional names.

From Figure 4 the Mathcad Properties page contains the following:

Message: Indicating the last date of the analysis. A message is shown if the model has been changed since the last time it was analyzed. Below the warning message is a title and description of the worksheet that is in the que to be run. The title and description are 100% user defined utilizing the native Windows file description object.

Results: The results section is a multi line return from Mathcad. Any concatenated string can be returned and listed here.

Definition: This section provides a drop down list of all the available Mathcad worksheets in the design binder. The path of the current selection is shown.

Dimension: This section contains all the dimensional values that are linked between StructureWorks Precast the current Mathcad 13 worksheet. In addition to the dimension names, the section also contains the current dimension values.

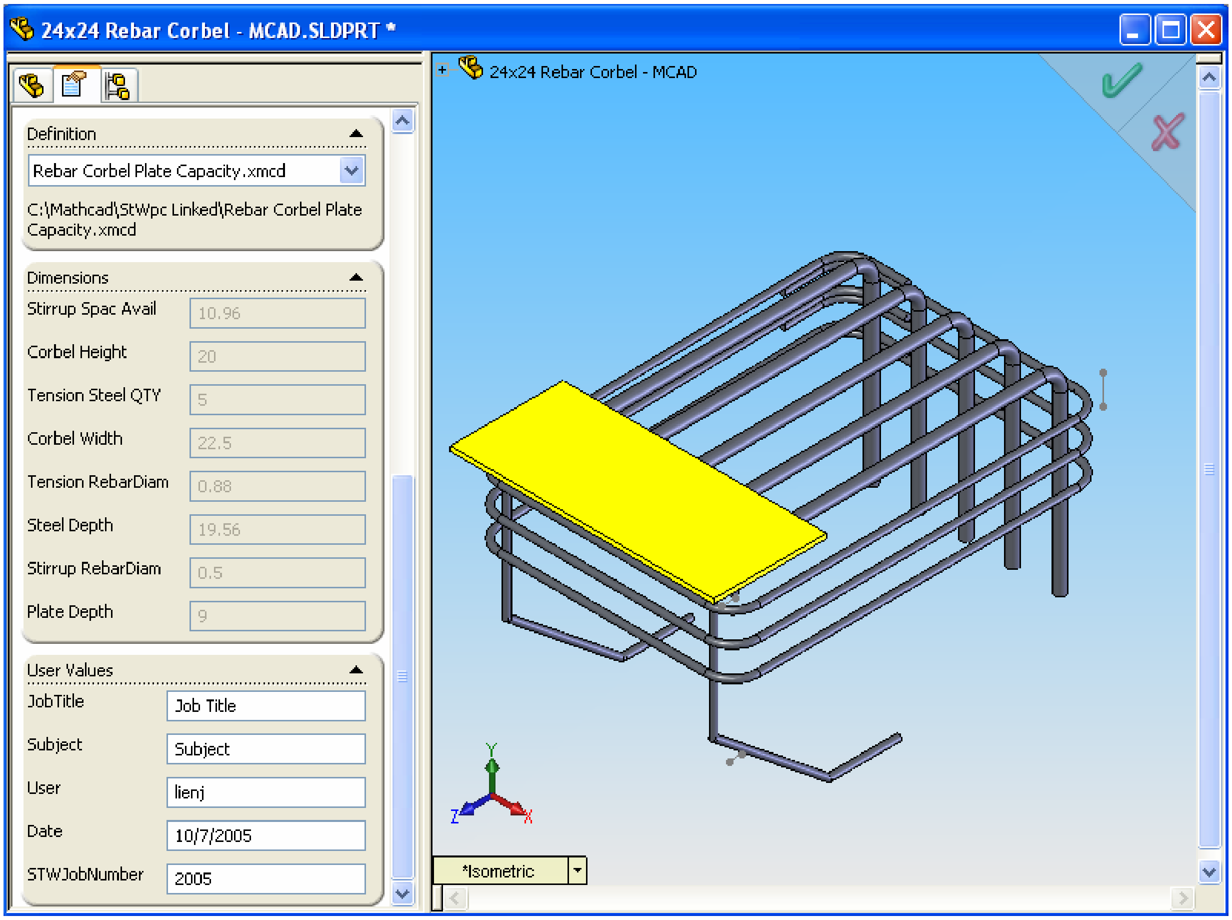
User Values: This section contains the additional values required for the design or analysis. This allows other inputs to be set without the need to tab between the applications.

Integration Samples

To demonstrate the process we will use a Rebar Corbel. In the first pass we investigate the concept of Capacity Checking and the second pass we investigate Automated Design. Capacity checking entails creating a model and determining the maximum design load, ϕV_n, based on the current model and some engineering parameters. Automated Design will automatically change the model, I.E. bar size, spacing, hook requirements, and weld based on a given set of parameters and the applied load, V_u.

Capacity Check

The following Rebar Corbel is modeled with the following geometry data listed in the property page on the left of the model in the Dimension Section. The User values are listed below in the User Value section. Even though any variable can be transferred between the applications, the engineering parameters that are required, f'_c, E_{st}, etc., are stored in the Mathcad Worksheet.



Definition

Rebar Corbel Plate Capacity.xmcd

C:\Mathcad\StWpc Linked\Rebar Corbel Plate Capacity.xmcd

Dimensions

Stirrup Spac Avail	10.96
Corbel Height	20
Tension Steel QTY	5
Corbel Width	22.5
Tension RebarDiam	0.88
Steel Depth	19.56
Stirrup RebarDiam	0.5
Plate Depth	9

User Values

JobTitle	Job Title
Subject	Subject
User	lienj
Date	10/7/2005
STWJobNumber	2005

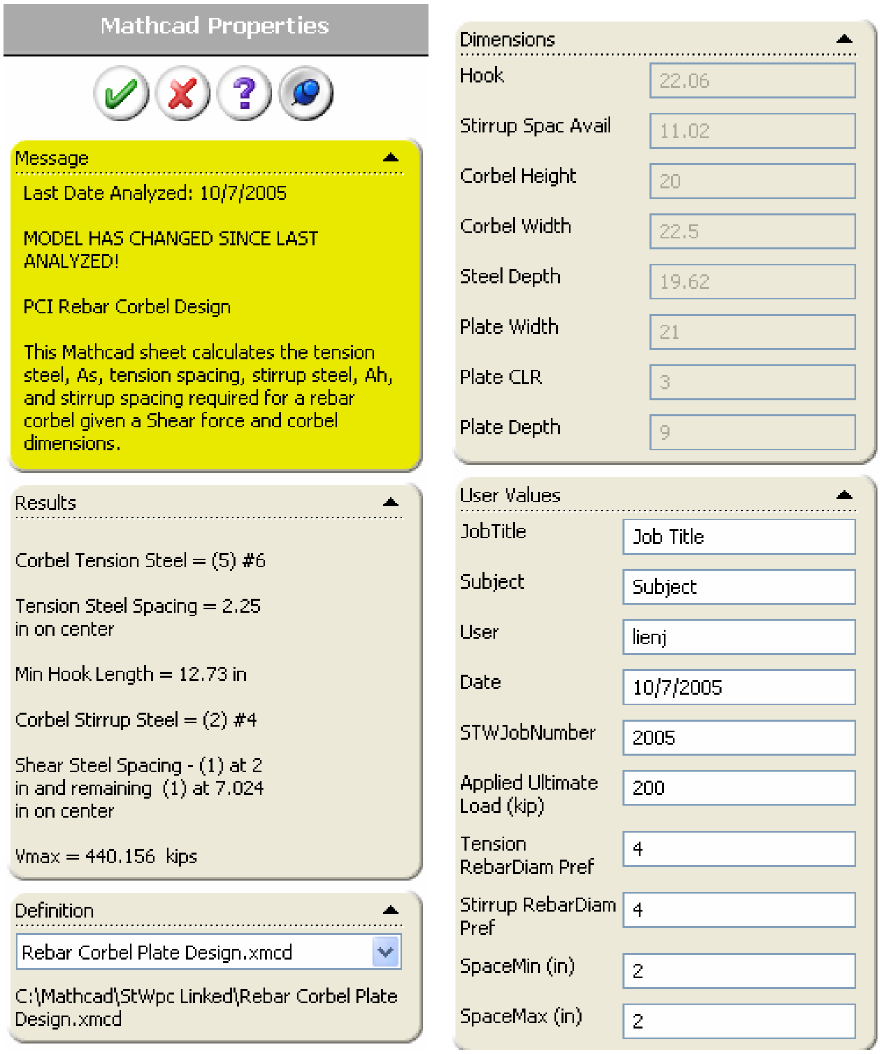
Figure 5 – Capacity Check Rebar Corbel Example

The Mathcad worksheet selected for the Analysis is *Rebar Corbel Plate Capacity.XMCD.*

On the Mathcad Properties page the dimensions and user values are listed. When the worksheet is calculated (the Green Check) the results section is populated with a user defined array in Mathcad.

Automated Rebar Corbel Design

Even though the model is the exact same, the Property Page shows more dimensional control and user values. New dimensions are sent to Mathcad for the automated layout routine. They include the Plate Width, Edge Clearance, and available Hook length. New User variables are introduced for Preferred Rebar Size, Minimum and Maximum Spacing, in addition to an applied Ultimate Load.



Message

Last Date Analyzed: 10/7/2005

MODEL HAS CHANGED SINCE LAST ANALYZED!

PCI Rebar Corbel Design

This Mathcad sheet calculates the tension steel, As, tension spacing, stirrup steel, Ah, and stirrup spacing required for a rebar corbel given a Shear force and corbel dimensions.

Results

Corbel Tension Steel = (5) #6

Tension Steel Spacing = 2.25 in on center

Min Hook Length = 12.73 in

Corbel Stirrup Steel = (2) #4

Shear Steel Spacing - (1) at 2 in and remaining (1) at 7.024 in on center

Vmax = 440.156 kips

Definition

Rebar Corbel Plate Design.xmcd

C:\Mathcad\StWpc Linked\Rebar Corbel Plate Design.xmcd

Dimensions

Hook	22.06
Stirrup Spac Avail	11.02
Corbel Height	20
Corbel Width	22.5
Steel Depth	19.62
Plate Width	21
Plate CLR	3
Plate Depth	9

User Values

JobTitle	Job Title
Subject	Subject
User	lienj
Date	10/7/2005
STWJobNumber	2005
Applied Ultimate Load (kip)	200
Tension RebarDiam Pref	4
Stirrup RebarDiam Pref	4
SpaceMin (in)	2
SpaceMax (in)	2

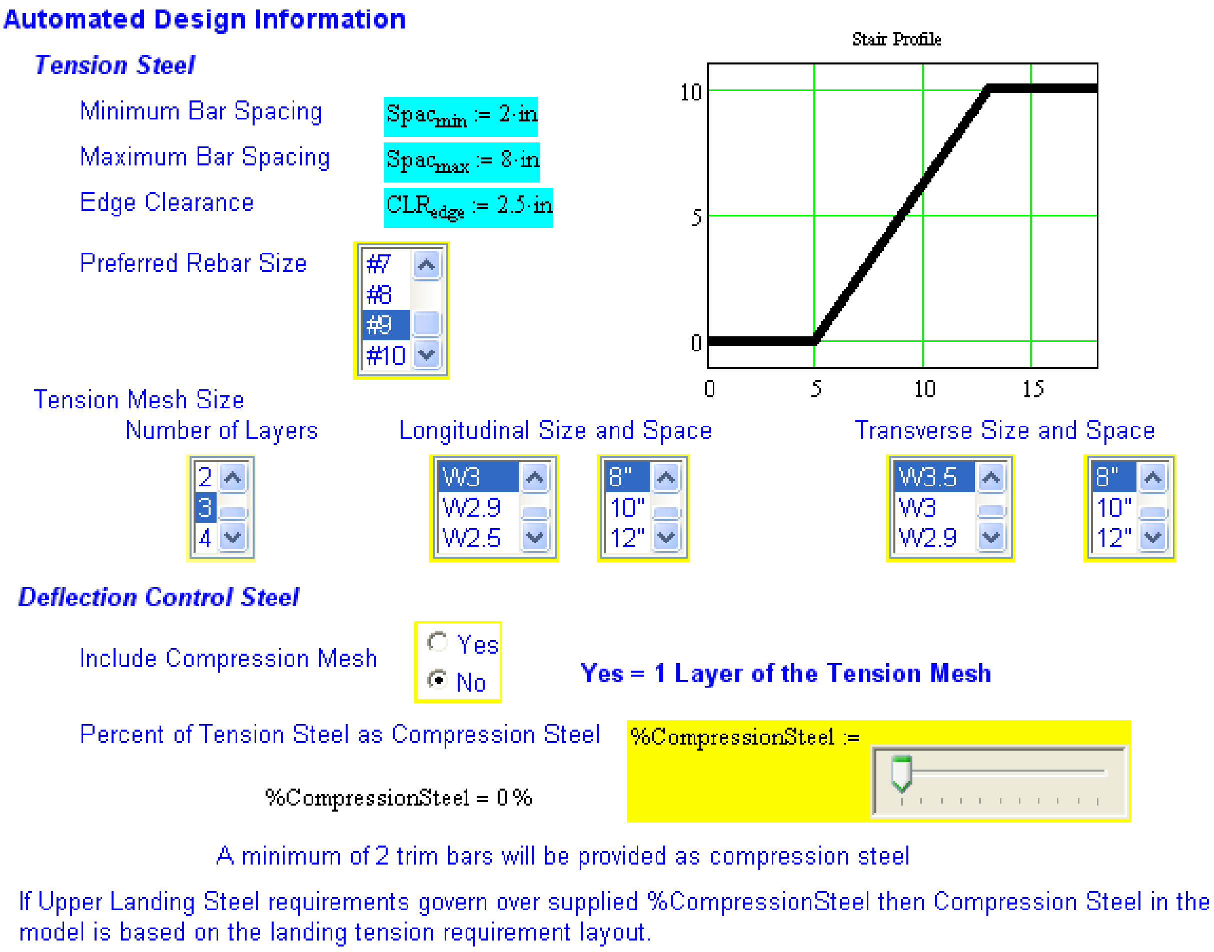
Figure 6 – Complete Automated Design Property Page

Automated Stair Design

Automated design has had limited success. Much of this is due to the complexity of what should be included in the design and how detailed and company specific can the output be. When one uses an application where the user has full control of all parameters, the user can create the custom design applications based on as few or as many design parameters. Within the Mathcad Worksheet the user can save standard values and only pass from StructureWorks Precast the required values for additional design data. The Worksheet in Appendix D is a program to design Precast Stair Units for Flexure.

Standard Variables

The standard options for Mesh in Tension and Compression in addition to the percentage of Tension Rebar used in Compression for Displacement control are all save in the worksheet. The yellow regions are standard options and for convenience the light blue regions are user inputs from StructureWorks Precast. See Figure 7.



Automated Design Information

Tension Steel

Minimum Bar Spacing $Spac_{min} := 2 \cdot in$

Maximum Bar Spacing $Spac_{max} := 8 \cdot in$

Edge Clearance $CLR_{edge} := 2.5 \cdot in$

Preferred Rebar Size: #9

Tension Mesh Size

Number of Layers: 3

Longitudinal Size and Space: W3, 8"

Transverse Size and Space: W3.5, 8"

Deflection Control Steel

Include Compression Mesh ○ Yes ● No

Yes = 1 Layer of the Tension Mesh

Percent of Tension Steel as Compression Steel $\%CompressionSteel :=$

$\%CompressionSteel = 0\%$

A minimum of 2 trim bars will be provided as compression steel

If Upper Landing Steel requirements govern over supplied %CompressionSteel then Compression Steel in the model is based on the landing tension requirement layout.

Figure 7 - Standard Automated Design Parameters

Top-Down Precast Dimensions

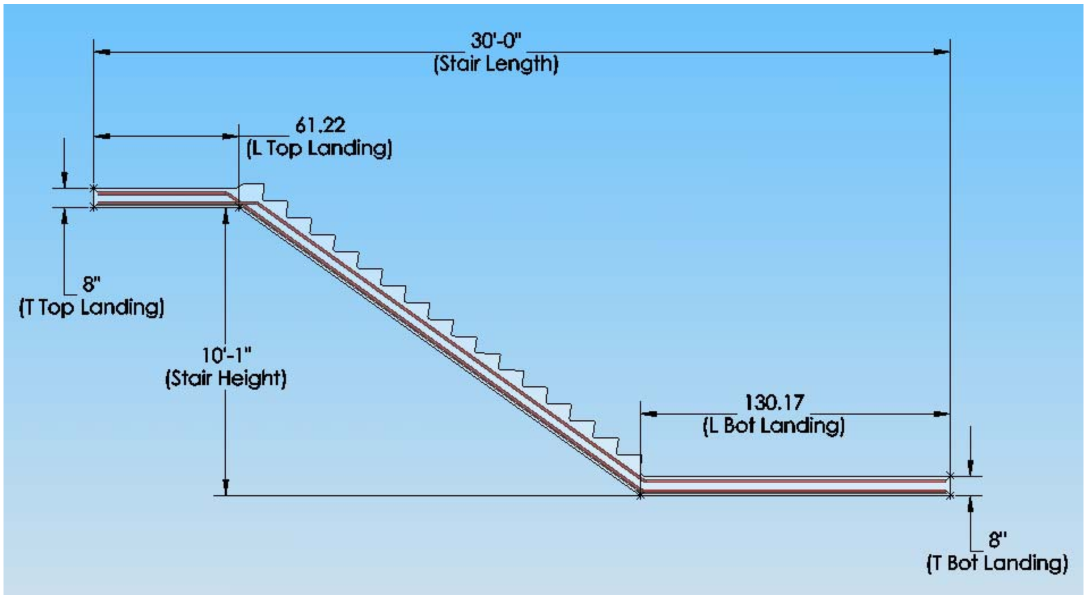


Figure 8 – Top-Down Reference Design Parameters

Conclusion

Buildings are complex. Engineering and designing them inherently contains risk. The integration presented in this paper allows the design engineer to develop and use current methods that many are comfortable with. Black box solutions have always been slow to be adopted while this method although the first of its kind, allows the user to expose as much or as little design validation as they choose. Checking the data transfer and adjusting the dimensional values required for the integration, requires limited effort on the part of the designer.

StructureWorks Precast has been shown to reduce risk across the entire enterprise; this is one additional area for greater returns and increased productivity. The transition from 2-D to 3-D is a difficult one, but by selecting the proper tool the transition can be simple, fast, and beneficial.

StructureWorks, LLC
5801 N. Pecos Street
Denver, Colorado 80221
303.278.4111

www.structureworks.net
info@structureworks.net

Appendix A

Rebar Corbel Plate Capacity Mathcad Worksheet

Job Title	Job Title	**By**	lienj	**Job Number**	2005
Subject	Subject	**Date**	10/7/2005	**Sheet**	**of**

Rebar Corbel Capacity

Corbel Height	$CorbelHeight := 20 \cdot in$	Qunatity of Tension Bars	$SteelQTY := 5$
Corbel Width	$CorbelWidth := 22.5 \cdot in$	Diameter of Tension Bars	$SteelRebarDiam := 0.875\,in$
Effective Depth	$SteelDepth := 19.562\,in$	Diameter of Shear Stirups	$StirrupRebarDiam := 0.500\,in$
Plate Depth	$PlateDepth := 9 \cdot in$		

Input

Load Ratio	$Ratio := 20\%$	Material Data	$\phi := .85$ $\quad \lambda := 1.0$ $\quad f_y := 60 \cdot ksi$ $\quad f'_c := 5000\,psi$
Load Eccentricity	$e := PlateDepth \cdot 75\%$		$\mu := 1.4$ (Monolithic corbels)

Calculations

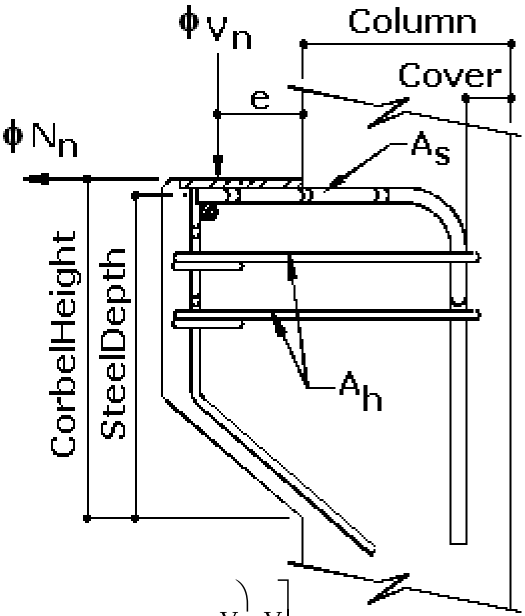
Area of Crack Interface $\quad A_{cr} = 440.145\,in^2$

Total Tension Steel $\quad A_s = 3\,in^2$

Maximum Shear

$$\mu \lambda f'_c = 1000\,psi$$

$$\phi V_{n_1} := \mu \lambda f'_c \cdot \left(\lambda^2 \cdot A_{cr}\right) \qquad \phi V_{n_1} = 440.145\,kip$$



Capacity Based on Cantilever Bending

$$\phi V_{n_2} := \frac{\phi \cdot A_s \cdot f_y \cdot d}{e + Ratio \cdot (H - d) + Ratio \cdot d} \qquad \phi V_{n_2} = 278.417\,kip$$

Capacity Based on Shear Friction

$$\phi V_{n_3} := root\left[\left(\frac{\dfrac{\phi \cdot A_s \cdot f_y}{2}}{3 \cdot if\left(\dfrac{1000 \cdot psi \cdot \lambda \cdot A_{cr} \cdot \mu}{V} > 3.4, 3.4, \dfrac{1000 \cdot psi \cdot \lambda \cdot A_{cr} \cdot \mu}{V}\right) + Ratio} - V\right), V\right] \qquad \phi V_{n_3} = 294.819\,kip$$

PCI Equation 6.8.6 $\quad A_h := .5 \cdot \left(A_s - \dfrac{Ratio \cdot min(\phi V_n)}{\phi \cdot f_y}\right)$

PCI Equation 6.8.5 - Minimum Area of Steel $\quad As_{min} = 1.467\,in^2$

Output

Design Capacity	$\phi Vn = 278.42\,kip$
Quantity of Stirups required for Design Capacity	$QTYStirrup = 3$
Amount of Horizontal Tie steel required for design capacity	$A_h = 0.954\,in^2$

Horizontal Ties Should be distributed within the top $\frac{2}{3} \cdot d = 13.041\,in$ of the main tension steel

Appendix B

Automated Stair Unit Design Mathcad Worksheet

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Denver, Colorado 80221
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Job Title	Job Title	**By**	Eng	**Job Number**	Job#
Subject	Subject	**Date**	10/10/2005	**Sheet**	of

Stair Dimensions

Landing Lengths

$L_{landing\_top} := 60 \cdot in$ $L_{landing\_bottom} := 60 \cdot in$

Landing Thickness

$t_{landing\_top} := 8 \cdot in$ $t_{landing\_bottom} := 8 \cdot in$

Stair Width $Width := 60 \cdot in$

Total Elevation Change $Height := 121 \cdot in$

Total Horizontal Length $Length := 18 \cdot ft$

Load and Steel Design Parameters

ACI Design Code $DC := \text{"318-99"}$

Compression Block Width $b := Width$

Landing Topping Thickness $Land_{Top} := 2 \cdot in$

Effective Steel Depth $d := 6.5in$

Live Load $P_{LL} := 100 \cdot psf$

Steel Yield Strength $f_y := 60 \cdot ksi$

% Live Load Sustained $\%_{LL} := 10\%$

Concrete Strength $f'_c := 5000 \cdot psi$

Concrete Unit Weight $\gamma_c := 150 \cdot pcf$

Section Height $h := 8.5 \cdot in$

Steel Modulus $E_{st} := 29000 \cdot ksi$

Concrete Modulus $E_c = 4286.826\,ksi$

Step Section Area (7x11) $A_{step} := 141.35 \cdot in^2$

Automated Design Information

Tension Steel

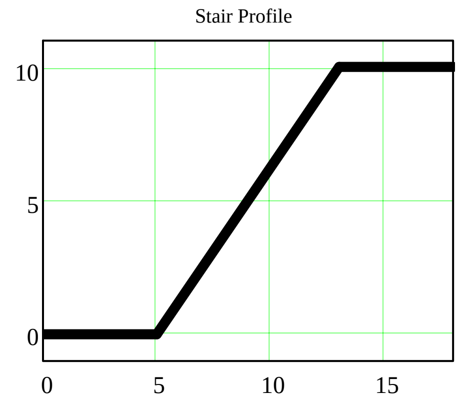
Minimum Bar Spacing $Spac_{min} := 2 \cdot in$

Maximum Bar Spacing $Spac_{max} := 8 \cdot in$

Edge Clearance $CLR_{edge} := 2.5 \cdot in$

Preferred Rebar Size

#7
#8
#9
#10



Tension Mesh Size

Number of Layers	Longitudinal Size and Space		Transverse Size and Space	
2 3 4	W3 W2.9 W2.5	8" 10" 12"	W3.5 W3 W2.9	8" 10" 12"

Deflection Control Steel

Include Compression Mesh ○ Yes ● No

Yes = 1 Layer of the Tension Mesh

Percent of Tension Steel as Compression Steel $\%CompressionSteel :=$ 0

$\%CompressionSteel = 0\,\%$

A minimum of 2 trim bars will be provided as compression steel

If Upper Landing Steel requirements govern over supplied %CompressionSteel then Compression Steel in the model is based on the landing tension requirement layout.

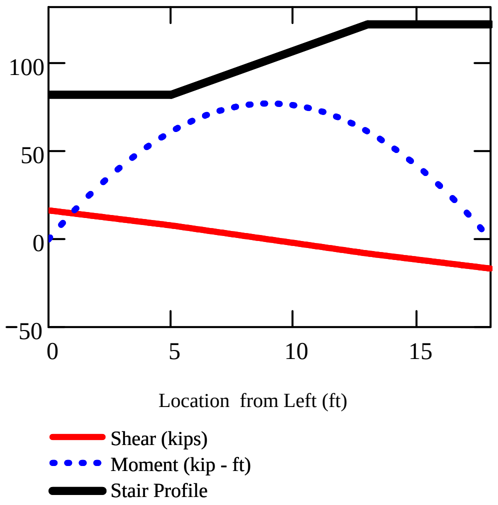
End Reactions

Left Working $\max\left(R_L^{\langle 1\rangle}\right) = 10.938\,\text{kip}$ Right Working $\max\left(R_R^{\langle 1\rangle}\right) = 10.938\,\text{kip}$

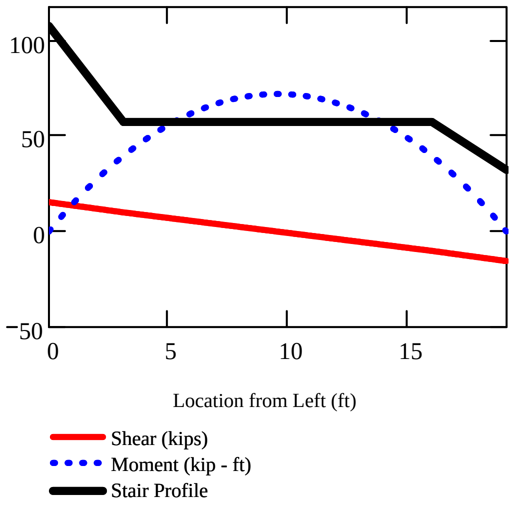
Left Ultimate $\max\left(R_L^{\langle 2\rangle}\right) = 16.663\,\text{kip}$ Right Ultimate $\max\left(R_R^{\langle 2\rangle}\right) = 16.663\,\text{kip}$

Shear and Ultimate Moment Diagrams

Ultimate V and M Parallel To Landings



Ultimate V and M Parallel To Steps



Maximum Moments and Steel Requirements

Ultimate

Parallel To Landing $M_{max_{1,2}} = 933.95\,\text{kip}\cdot\text{in}$ Location $X_{max_{1,2}} = 9\,\text{ft}$

Parallel To Stairs $M_{max_{2,2}} = 867.249\,\text{kip}\cdot\text{in}$ Location $X_{max_{2,2}} = 9.543\,\text{ft}$

Steel Requirements

$$\text{MainRequirements} = \begin{pmatrix} \text{"2.803 sq. in Flexural Steel Required"} \\ \text{"0.9 Strength Reduction Factor"} \\ \text{"13.08 sq. in Balanced Steel "} \\ \text{"9.81 sq. in Maximum Steel based on 75\% of Balanced Steel "} \\ \text{"1.379 sq. in Minimum Steel Required "} \\ \text{"0.918 sq. in Longintudinal Shrinkage and Temperature Steel Required"} \end{pmatrix}$$

Top Landing Moments at Landing Stair Interface

Parallel To Landing $M_{Landing\_max_1} = 741.039\,\text{kip}\cdot\text{in}$

Parallel To Stairs $M_{Landing\_max_2} = 476.923\,\text{kip}\cdot\text{in}$

Steel Requirements

$$\text{LandingRequirements} = \begin{pmatrix} \text{"2.199 sq. in Flexural Steel Required"} \\ \text{"0.9 Strength Reduction Factor"} \\ \text{"13.08 sq. in Balanced Steel "} \\ \text{"9.81 sq. in Maximum Steel based on 75\% of Balanced Steel "} \\ \text{"1.379 sq. in Minimum Steel Required "} \\ \text{"0.918 sq. in Longintudinal Shrinkage and Temperature Steel Required"} \end{pmatrix}$$

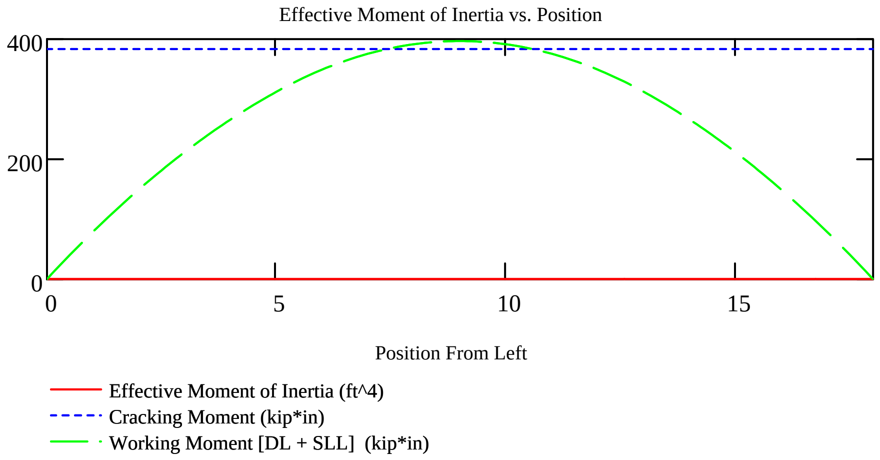
Deflections Based on Profile Parallel to Landing

Gross Moment of Inertia $I_g(b,h) = 3070.625\,in^4$

Cracked Transformed Moment of Inertia $I_{cr}\left(b,d,E_{st},f'_c,\gamma_c,A_{Total\_Supplied}\right) = 1235.548\,in^4$

Cracking Moment $M_{cr}\left(f'_c,b,h\right) = 383.163\,kip\cdot in$

Effective Moment of Inerta as a function of Position (through applied Moment)



Location of Maximum Deflection $\xi = 9\ ft$

Long Term Modifier $\lambda = 1.592$

Initial Deflection Due to DL and Sustained LL $\delta(\xi) = 0.147\ in$

Final Delfection @ Due to DL and Sustained LL $\delta(\xi) + \lambda\cdot\delta(\xi) = 0.381\ in$

Deflection Limits $\frac{L_1}{360} = 0.6\,in$

Final Steel Design

Required Tension Steel $A_{sdesign} = 2.803\ in^2$

Tension Steel Design

$A_{Total\_Supplied} = 8.619\ in^2$

TensionSteel = "(8) #9 @ 7.857" on center"

$A_{rb\_Supplied} = 8\ in^2$

TensionMesh = "(3) Layer of 8 x 8 - W3 x W3.5"

$A_{mesh\_Supplied} = 0.619\ in^2$

Compression Steel Design

$Ac_{Total\_Supplied} = 2\ in^2$

CompressionMesh = "No Compresion Mesh in Design"

$Ac_{rb\_Supplied} = 2\ in^2$

CompressionSteel = "(2) #9 @ 55" on center"

$Ac_{mesh\_Supplied} = 0\ in^2$

Required Landing Tension Steel $A_{sLandingdesign} = 2.199\ in^2$

Landing Steel Design

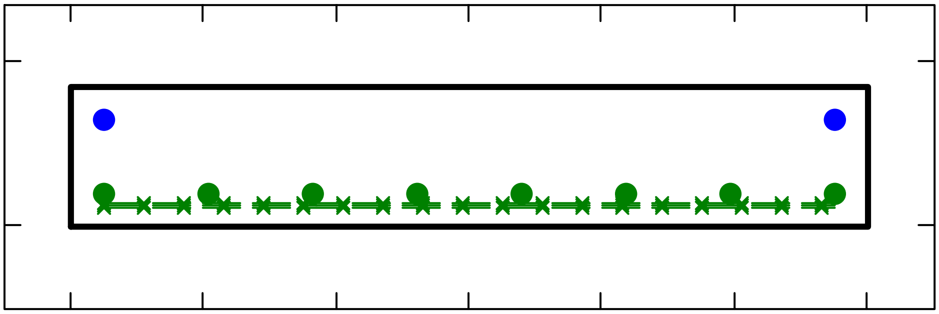
LandingSteel = "(8) #9 @ 7.857" on center"

$A_{landing\_Supplied} = 8\ in^2$

Stair Section Design Summary

Tension Steel (GREEN)	Compression Steel (BLUE)
(8) #9 @ 7.857" on center	**(2) #9 @ 55" on center**
(3) Layer of 8 x 8 - W3 x W3.5	**No Compresion Mesh in Design**

Cross Section / Rebar Layout

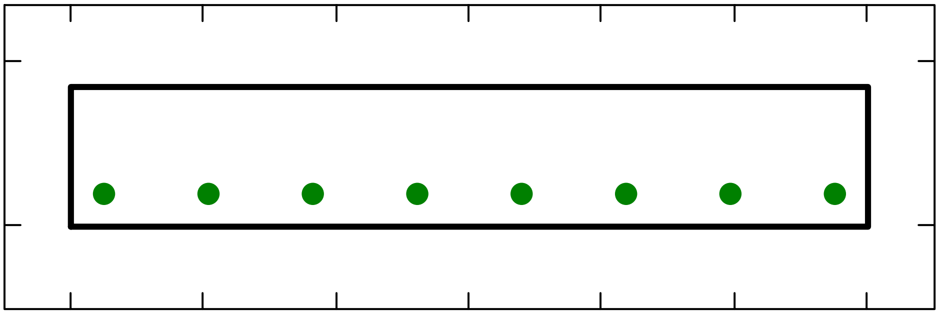


Landing Section Design Summary

Landing Steel (if Required)

(8) #9 @ 7.857" on center

Cross Section / Rebar Layout



Concrete Properties

28 Day Strength $f'_c = 5000\,psi$

Release Strength $f_{ci} := 2500 \cdot psi$